Int j simul model 22 (2023) 1, 76-87
Original scientific paper

NOVEL DISPATCHING RULES FOR MULTIPLE-LOAD AUTOMATED GUIDED VEHICLES

Isik, M.; Sahin, C. & Hamidy, S. M.
University of Cukurova, Faculty of Engineering, Department of Industrial Engineering,
01330, Adana, Turkey
E-Mail: demirtasm@cu.edu.tr, cenksahin@cu.edu.tr, sakhimh@gmail.com

Abstract

Managing the manufacturing systems and establishing scheduling is a dynamic process that must be handled properly in the event that unexpected events arise. Scheduling manufacturing systems requires not only considering the availability of machines, but also their material handling systems. In a dynamic manufacturing environment, dispatch rules are commonly used in scheduling machines and material handling systems. Multiple-load Automated Guided Vehicles (MAGVs) handle multiple loads. There is a discussion of problems associated with MAGVs, including task determination, delivery, pickup, and load selection. In this study, new rules for determining tasks, determining delivery routes, and selecting loads are proposed and investigated. The proposed rules are evaluated using simulation models with two performance criteria: makespan and lateness, in comparison with the rules presented in the literature as the best. According to the results, the proposed rules result in schedules with the shorter makespan and shorter lateness.

(Received in August 2022, accepted in November 2022. This paper was with the authors 1 week for 1 revision.)

Key Words: Multiple-Load Automated Guided Vehicles (MAGVs), Dispatching Rules, Simulation

1. INTRODUCTION

Manufacturing scheduling problems have been studied extensively in recent years. The scheduling problem in manufacturing systems has been addressed in a number of ways, such as through mathematical models [1, 2]. Due to the dynamic nature of manufacturing systems, the scheduling process must be handled when unexpected events arise, such as new jobs and changing capacity. When these kinds of events occur, scheduling manufacturing systems becomes difficult, and dispatching rules are frequently used instead of mathematical models. Besides these events, other factors such as availability of machines and vehicles, which are main components of manufacturing systems, are also taken into consideration when making schedules. Sabuncuoglu and Hommertzheim [3] addressed the simultaneous scheduling of processing machines and vehicles. It was necessary to schedule machining and handling systems simultaneously due to their interaction. In manufacturing systems, Automated Guided Vehicles (AGVs) are used for transporting materials between resource units and destination units. AGVs with multiple loads (MAGVs) handle multiple jobs in a different manner from traditional AGVs that handle one job. The simulation method was used by Ozden [4] to investigate the effect of several key MAGVs-related factors on the performance of a Flexible Manufacturing System (FMS). Following this study, the effect of different dispatching rules in the case of MAGVs and an extended modelling algorithm were studied [5, 6]. A number of studies have been conducted in the job shop environment on the scheduling problem of MAGVs [7, 8]. In the study of Murayama and Kawata [9], the processing machines and MAGVs were scheduled simultaneously.

MAGV systems are also investigated in two layout configurations: unidirectional and segmented bi-directional single loop [10, 11]. A tandem layout using unidirectional guide-path loops and multiple-load vehicles was studied by Ho and Hsieh [12]. In a later study, Ho and Chien [13] examined directional guide-paths and defined four problems, including task determination, delivery, pickup, and load selection. In MAGVs, these problems are listed and

https://doi.org/10.2507/IJSIMM22-1-632

highlighted. In the task determination problem, it is necessary to decide whether it is a pickup or delivery task. Delivery dispatching problem determines which delivery point should be visited next, and pickup dispatching problem determines which pickup point should be visited next. As a last step, the load selection problem involves selecting loads from a pickup point's output queue to fill. A task determination rule and a delivery dispatching rule were proposed by Ho and Chien [13]. Afterward, Ho and Liu investigated pickup dispatching and load selection rules [14, 15]. As a final note, Ho et al. [16] proposed a new method to deal with the problem of picking up and loading MAGVs based on the method of pickup and load selection. Recent simulation studies have been conducted by Li and Kuhl [17] and Chawla et al. [18] for task determination. A simulation model was developed by Lee et al. [19] for avoiding collisions in MAGVs. A study by Guan et al. [20] investigated the multistage auction algorithm, and Angra et al. [21] discussed simulation results for MAGVs in a changing FMS design. Based on the dial-a-ride problem model, Boden et al. [22] discussed a dispatching approach for MAGVs. Yan et al. [23] developed a MAGV system based on an advanced form of Petri Nets to simulate various scenarios surrounding the operation of an AGV system.

AGV dispatching rules are divided into two categories by Egbelu and Tanchoco [24]: workstation-initiated rules, which select vehicles for pickup, and vehicle-initiated rules, which select workstations for delivery. This study proposes MAGV dispatch rules based on workstation-initiated rules that address four main problems. An analysis has been conducted about the effects of the proposed rules on the performance of the system, including the increase in the capacities of the MAGVs used. The task determination, delivery and load selection problem are chosen and new rules are developed to improve performance.

As for the rest of the study, it is arranged as follows: In section 2, dispatching rules are presented. The results are then presented in section 3. Lastly, conclusion is presented.

2. DISPATCHING RULES

In order to make the best decision in the system, novel rules have been developed for task determination, delivery, and load selection problems. Using simulation modelling, the rules are applied and results are analysed. Notation for the parameters and variables in developed rules is indicated in Table I.

According to previous studies, when both loading and unloading tasks are available, the Delivery Task First (DTF) rule is found to be the best for MAGVs. MAGV always selects the load delivery for the next task in accordance with the DTF rule. MAGVs deliver loads by using the Shortest Distance (SD) rule. It should be noted that if the MAGVs are unable to perform the DTF rule, they carry out the second condition, Pickup Task First (PTF) rule and they search for loads to pick up. As a pickup rule, MAGVs utilize the Greatest Output Queue (GOQ) rule. In this rule, the station with the largest output queue is selected for picking up. Loads at a pickup station are selected according to a load selection rule when MAGVs arrive. Identical Destination (ID) rule is used in load selection task. In order to minimize the total travel distance, the ID rule prioritizes loads that have the same delivery points as the loads on the MAGV.

As part of this study, a new approach called New Delivery Task First (NDTF) rule is proposed (Algorithm 1) for task determination problem of MAGVs. In accordance with the rule, after completing a delivery task, MAGVs control the station’s pickup point and there will be a change to the new task to be picked up, if there is one. This allows the MAGV’s capacity to be utilized effectively.

Table I: Notation of rules.

Indices	
j	Index of stations
i	Index of MAGVs
p	Index of loads
Parameters	
Q	The total number of stations
c_i	The load capacity of MAGV i
T	Simulation end time
e_d	$\begin{cases} 1, & \text{If the delivery dispaching rule is Shortest Distance} - \text{SD} \\ 2, & \text{If the delivery dispaching rule is New Shortest Distance} - \text{NSD} \end{cases}$
r_l	$\begin{cases} 1, & \text{If the load selection rule is Identical Destination} - \text{ID} \\ 2, & \text{If the load selection rule is New Identical Destination} - \text{NID} \end{cases}$
Variables	
t	Current simulation time
l_{it}	The number of loads on the MAGV i at the time t
m_j	The number of loads waiting in the output queue of station j
LC_{ip}	The station to which load p on MAGV i is delivered
q_{jp}	The station to which load p in the output queue of station j is delivered
$Dis(LC_i, LC_{ip})$	Distance between the station to which load p is delivered and current location MAGV i
a_{jt}	$\begin{cases} 1, & \text{If station } j \text{ place a pickup request at time } t \\ 0, & \text{otherwise} \end{cases}$
b_{jt}	$\begin{cases} 1, & \text{If station } j \text{ place a delivery request at time } t \\ 0, & \text{otherwise} \end{cases}$

Algorithm 1 New Delivery Task First Rule

```
procedure $NDTF(l_{it}, c_i, m_j, b_{jt}, i, j, e_d, r_l, LC_{ip}, q_{jp}, T, Q)$
  for $t$ =1 to $T$ do
    if $l_{it} > 1$ then
      if $b_{jt} == 1$ //apply delivery rule
          if $e_d$ == 1 then apply SD($l_{it}, i, j, LC_{ip}$)
          if $e_d$ == 2 then apply NSD($l_{it}, c_i, m_j, i, j, LC_{ip}, q_{jp}$)
          send MAGV $i$ to selected station $j$
          for $p$ =1 to $l_i$ do
              if $LC_{ip} == j$ then
                  load $p$ from MAGV $i$ to input queue of station $j$
              end if
          end for
          if $m_j > 0$ then
            do until ($c_i == l_{it}$ or $m_j == 0$)
                  if $r_l$ == 1 then apply ID($i, l_{it}, c_i, m_j, q_{jp}, LC_{ip}$)
                  if $r_l$ == 2 then apply NID($i, l_{it}, c_i, m_j, q_{jp}, LC_{ip}$)
              loop
          end if
      end if
    else
      if $sum(j, m_j) == 0$ then
        hold until $sum(j, m_j) > 0$
      end if
      apply  GOQ($i, m_j, Q$)
```

```
25:         do until ($c_i == l_{it}$ or $m_j == 0$)
26:            if $r_l == 1$ then apply ID($i, l_{it}, c_i, m_j, q_{jp}, LC_{ip}$)
27:            if $r_l == 2$ then apply NID($i, l_{it}, c_i, m_j, q_{jp}, LC_{ip}$)
28:         loop
29:    end for
30: end procedure
```

The second rule recommended for the task determination problem is called the New Pickup Task First (NPTF) rule. This rule searches for all candidate pickup loads in the output queue of the station where a delivery task has already been assigned. As soon as a pickup load is found to be suitable, it is designated as a new task. This is done by MAGV querying the loads on it and matching a pickup point with a delivery point. NPTF rule differs from PTF rule in this aspect (Algorithm 2).

Algorithm 2 New Pickup Task First Rule

```
1: procedure $NPTF(l_{it}, c_i, m_j, a_{jt}, i, j, T, Q, LC_{ip}, q_{jp}, r_l, e_d)$
2:     for $t$ =1 to $T$ do
3:        if $c_i > l_{it}$ then
4:           if $sum(j, m_j) > 0$ then
5:              if $a_{jt} == 1$ //apply pickup rule
6:                 apply GOQ($i, m_j, Q$)
7:                 for $p$ =1 to $l_{it}$ do
8:                    if $LC_{ip} == j$ then
9:                       load $p$ from MAGV $i$ to input queue of station $j$
10:                   end if
11:                end for
12:                do until ($c_i == l_{it}$ or $m_j == 0$)
13:                   if $r_l == 1$ then apply ID($i, l_{it}, c_i, m_j, q_{jp}, LC_{ip}$)
14:                   if $r_l == 2$ then apply NID($i, l_{it}, c_i, m_j, q_{jp}, LC_{ip}$)
15:                loop
16:             end if
17:          else
18:             hold until $sum(j, m_j) > 0$
19:                go to line_5
20:          end if
21:       else
22:          if $e_d == 1$ then apply SD($l_{it}, i, j, LC_{ip}$)
23:          if $e_d == 2$ then apply NSD($l_{it}, c_i, m_j, i, j, LC_{ip}, q_{jp}$)
24:          send MAGV $i$ to selected station $j$
25:          for $p$ =1 to $l_{it}$ do
26:             if $LC_{ip} == j$ then
27:                load $p$ from MAGV $i$ to input queue of station $j$
28:             end if
29:          end for
30:          if $m_j > 0$ then
31:             do until ($c_i == l_{it}$ or $m_j == 0$)
32:                if $r_l == 1$ then apply ID($i, l_{it}, c_i, m_j, q_{jp}, LC_{ip}$)
33:                if $r_l == 2$ then apply NID($i, l_{it}, c_i, m_j, q_{jp}, LC_{ip}$)
```

```
                loop
            end if
        end if
    end for
end procedure
```

When there are loads waiting for pickup on the same route, the proposed New Shortest Distance (NSD) rule ensures that the MAGV completes its path by selecting from them (Algorithm 3). The proposed New Identical Destination (NID) rule selects the first load in the output queue of the station if there are no loads with the same delivery points as the loads on the MAGV, and then continues to select loads with the same or nearest delivery points (Algorithm 4). If there is more free capacity on the MAGV, the First in First out (FIFO) principle is applied to fill the free capacity. The procedure is concluded at this point.

Algorithm 3 New Shortest Distance Rule

```
procedure $NSD(l_{it}, c_i, m_j, i, j, LC_{ip}, q_{jp})$
    $y = inf$
    for $p$=1 to $l_{it}$ do
        if Dis($LC_i, LC_{ip}$)< $y$ then
            delivery_final_destination = $LC_{ip}$
            y= Dis($LC_i, LC_{ip}$)
        end if
    end for
    set route_points() according to delivery route to delivery final destination
    for each $j$ in route_points
        if route_point($j$) != delivery_final_destination then
            if ( $c_i > l_{it}$ ) and ( $m_j > 0$) then
                do until ( $c_i == l_{it}$ or $m_j$== 0)
                    if $r_l$ == 1 then apply ID($i, l_{it}, c_i, m_j, q_{jp}, LC_{ip}$)
                    if $r_l$ == 2 then apply NID($i, l_{it}, c_i, m_j, q_{jp}, LC_{ip}$)
                loop
            end if
        else:
            for $p$ =1 to $l_{it}$ do
                if $LC_{ip}$== $j$ then
                    load $p$ from MAGV $i$ to input queue of station $j$
                end if
            end for
            if $m_j$ > 0 then
                do until ($c_i == l_{it}$ or $m_j$== 0)
                    if $r_l$ == 1 then apply ID($i, l_{it}, c_i, m_j, q_{jp}, LC_{ip}$)
                    if $r_l$ == 2 then apply NID($i, l_{it}, c_i, m_j, q_{jp}, LC_{ip}$)
                loop
            end if
        end if
    end for
end procedure
```

Algorithm 4 New Identical Destination Rule

```
procedure $NID(i, l_{it}, c_i, m_j, q_{jp}, LC_{ip})$
    if $l_i == 0$ then
        load $1^{st}$ load to the MAGV $i$
    end if
    do until $(c_i == l_{it}$ or $m_j == 0)$
        apply ID$(i, l_{it}, c_i, m_j, q_{jp}, LC_{ip})$
    loop
end procedure
```

3. RESULTS

Simulation modelling and analysis are commonly used in manufacturing to mimic system behaviour and test proposed rules [25, 26]. Simulation models are developed to implement and evaluate the proposed rules for MAGVs. To provide feedback on the performance of the proposed rules, and to determine whether the proposed rules can follow the solution paths provided in the literature, the manufacturing system proposed by Ho and Chien [13], including 3 of MAGVs with 4 load capacity are used as a base case for benchmarking. The base case including twelve workstations available on the system as a basis for scheduling. Workstation 1 is the entry station, workstations 2 to 11 are the processing stations, and workstation 12 is the exit station.

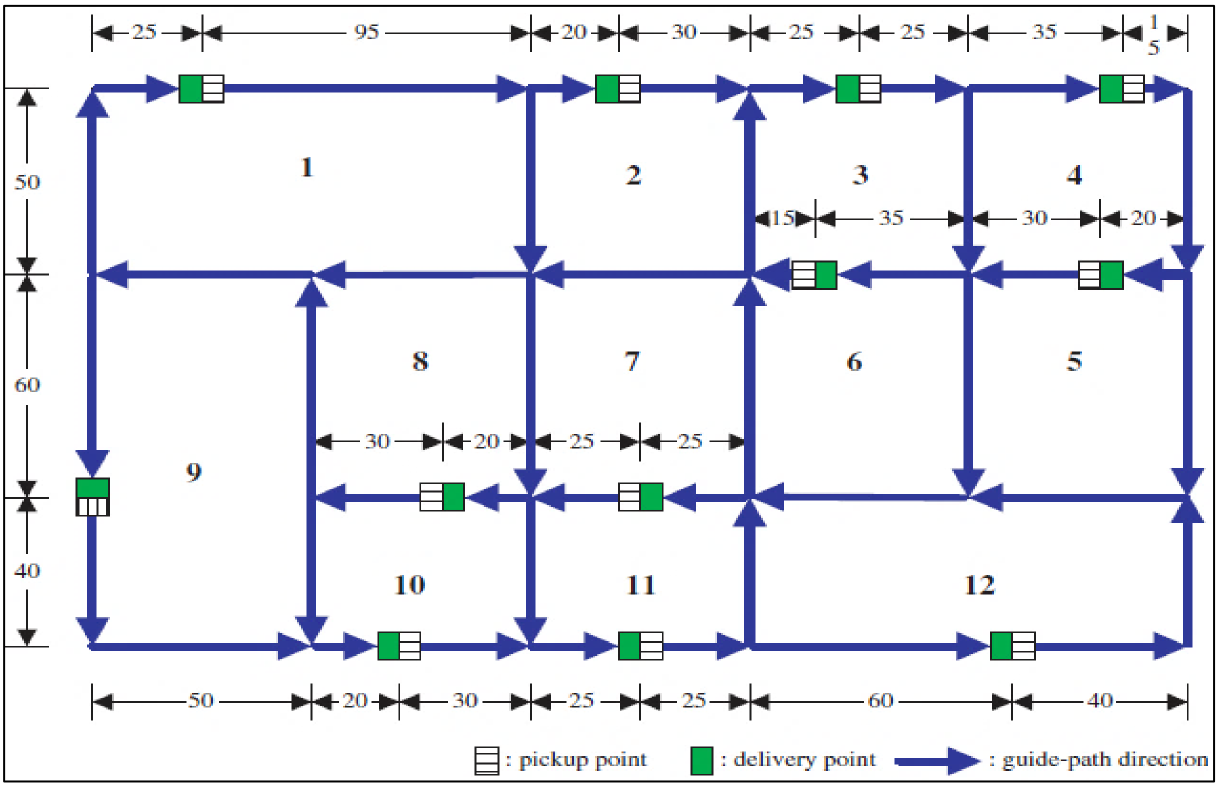


Figure 1: Manufacturing facility layout [13].

Fig. 1 illustrates the manufacturing facility layout used in simulation models. Loading or unloading is processed by an MAGV in 30 seconds. As shown in Table II, there are six different types of parts in manufacturing, each with its own operation sequence in stations and production volume.

Table II: Operation sequence [13].

Part type	**Production volume** (%)	**Operation sequence in stations**
1	16	1-3-5-7-9-11-12
2	17	1-2-4-6-8-10-12
3	18	1-4-5-7-9-10-12
4	15	1-3-4-5-9-11-12
5	14	1-2-3-6-8-9-12
6	20	1-5-6-7-10-11-12

As shown in Table II, production volume is summarized by part type, and Table III shows the processing time distribution at each workstation.

Table III: Processing times [13].

Workstation	**Processing times** (min)	**Workstation**	**Processing times** (min)
2	Normal(1, 0.1)	7	Normal(2, 0.2)
3	Normal(1.5, 0.15)	8	Normal(1.5, 0.15)
4	Normal(2, 0.2)	9	Normal(1.5, 0.15)
5	Normal(1, 0.1)	10	Normal(2, 0.2)
6	Normal(2, 0.2)	11	Normal(1, 0.1)

The simulation models are based on the following assumptions:

- The system has a limited number of vehicles, and all vehicles (MAGV) can carry more than one load at a time.
- There is a defined layout, and the roads are one-way.
- There are delivery, standby, and pickup points for each machine.
- Based on the Nearest Vehicle rule, the system selects MAGVs closest to jobs. The arrival time of the machine jobs corresponds to the exponential distribution with a mean of 3.

A total of ten simulation models are developed and analysed, including novel rules. In addition, the models are tested in terms of different values of the number of vehicles, and the capacity of each vehicle. Ho and Chien [13] assume that three MAGVs are used, and each vehicle can carry four units. In this study, it is called base case. A sensitivity analysis was conducted to assess the impact of changing some structural parameters on the proposed rules and discuss managerial insights for the implementation of rules. The sensitivity analysis considered the number of MAGVs in the system (2, 3 and 4) and the loading capacity of MAGVs (3, 4 and 5 units).

Manufacturing systems can be designed to meet a variety of performance criteria. As performance metrics, makespan and lateness time are taken into consideration. From the entry of the first job to the exit of the last job, the makespan time is calculated. The lateness time is calculated by assigning the due date with Eq. (1).

$$D_x = s_x + 3 * (\sum_{y=1}^{m} p_{xy} + Max\ t_{xy}) \tag{1}$$

where D_x denotes the due time of job *x*; s_x represents the arrival time for job *x*; p_{xy} and t_{xy} represent the processing time and transporting time operation *y* of job *x* respectively.

One of the key issues in the operation of the simulation model is determining the warm-up period. Warm-up periods can be measured in a variety of ways. An example would be the evaluation of a certain portion of the simulation time as a warm-up. As part of this study, the warm-up period is defined as the first 2000 jobs (30 % of the total number of jobs), and the analyses are evaluated by subtracting the values obtained from these jobs. Simulation is defined as completing 6000 jobs as a stop condition. The number of replications is calculated with Eq. (2) where e represents the number of experiments, $n_e^*(\gamma)$ represents the required number of replications; n represents the fixed number of replications, $t_{e-1,1-\alpha/2}$ is for t table value with n–1 degrees of freedom at α significance level, $\bar{X}(n)$ is mean, $S^2(n)$ is variance and $\gamma^I = \gamma/(1+\gamma)$ represents adjusted relative error of the mean [27].

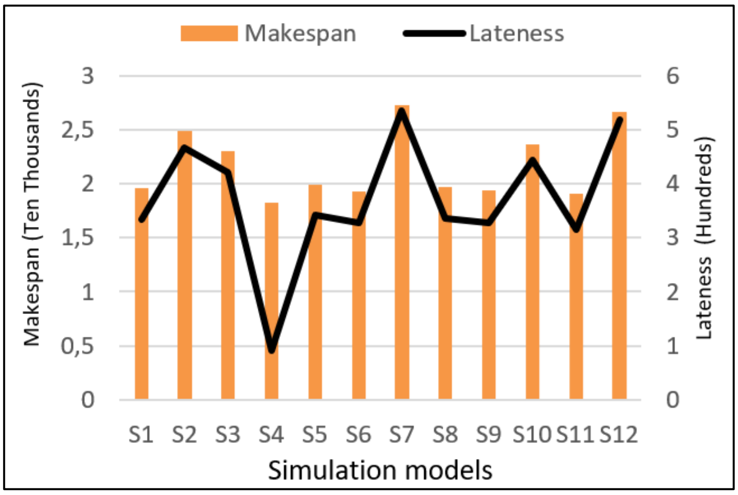
$$n_e^*(\gamma) = \left\{ e \geq n: \frac{t_{e-1,1-\alpha/2}\sqrt{S^2(n)/e}}{|\bar{X}(n)|} \right\} \leq \gamma^I \tag{2}$$

To determine the number of replications, a total of 20 replications are performed, and it is found to be sufficient. A total of 12 simulation models, S1 to S12 (Table IV), were developed to compare the proposed algorithms with those suggested in the literature. The first simulation model (S1) includes DTF for task determination, SD for delivery, GOQ for pickup, and ID for load selection rules. As for the second simulation model, it consists of the PTF for task determination, SD for delivery, GOQ for pickup, and ID for load selection rules, proposed by Ho and Chien [13]. Models from S3 to S12 are simulation models that run new rules and their different combinations. Table IV illustrates these simulation models and rules for four different problems in each model.

Table IV: Simulation models.

Simulation scenarios	**Dispatching rules**			
	1 – Task determination	**2 – Delivery**	**3 – Pickup**	**4 – Load selection**
S1	DTF	SD	GOQ	ID
S2	PTF	SD	GOQ	ID
S3	NDTF	SD	GOQ	ID
S4	DTF	SD	GOQ	NID
S5	NDTF	SD	GOQ	NID
S6	DTF	NSD	GOQ	ID
S7	NPTF	SD	GOQ	ID
S8	NDTF	NSD	GOQ	NID
S9	DTF	NSD	GOQ	NID
S10	NDTF	NSD	GOQ	ID
S11	PTF	SD	GOQ	NID
S12	NPTF	SD	GOQ	NID

In Fig. 2, the simulation models are shown together with their respective makespan and lateness for the base case analysis. The simulation models including proposed rules generated lower makespan and lateness, as shown in Fig. 2. Among models, simulation model 4 called S4 has outperformed the others in terms of both performance metrics, followed by S11 while S7 is the worst. Adding the NID rule to the S4 model improved performance metrics due to a reduction in the queue length in the output or input stations as a consequence of improved load selection. This shows that proposed NID has important impact and leads to decrease in both performance metrics significantly. In the S8 model, combining the proposed rules of NDTF, NSD, and NID also improved performance metrics. In this way, MAGV mainly leaves the load on itself, increasing the usage rate and making processes start faster.

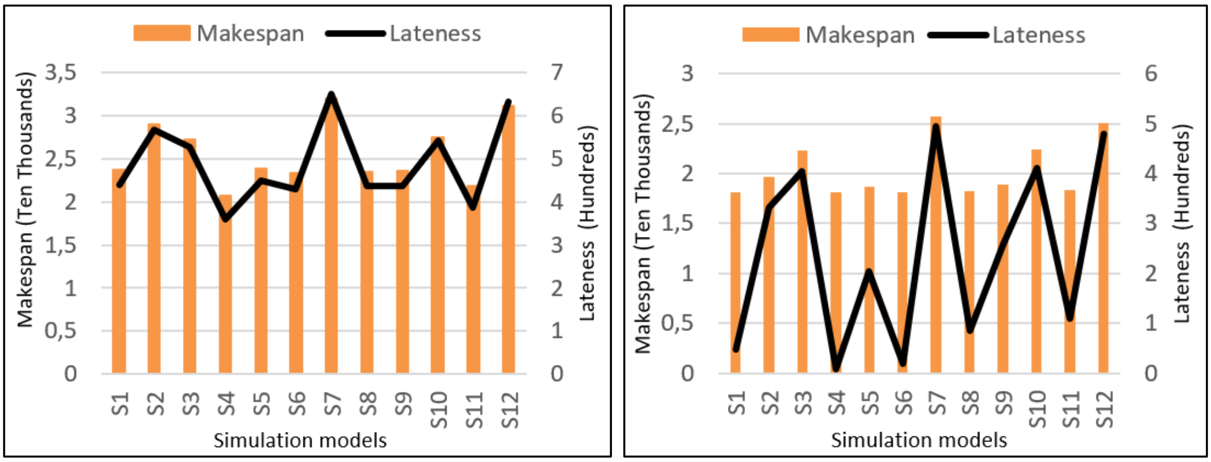


Simulation models	Makespan	Lateness
S1	19577	334
S2	24926	467
S3	23038	421
S4	**18210**	**92**
S5	19869	343
S6	19281	327
S7	27321	535
S8	19655	335
S9	19348	328
S10	23657	444
S11	19088	315
S12	26693	519

Figure 2: Comparison of the simulation models for the base case.

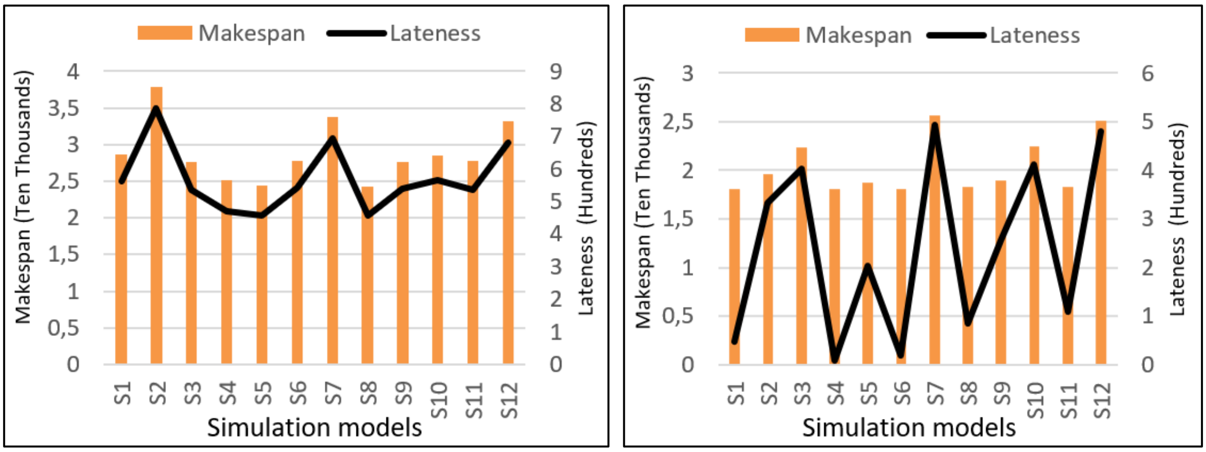
In addition to evaluating the results of the base case by changing some parameters, such as the number of MAGVs and carrying capacity, the simulation models were also subjected to a sensitivity analysis. Figs. 3 and 4 show the effects of increasing and decreasing parameters in different scenarios.

According to the results, in Fig. 3 a, the S4 and S11 models have the best performance at the loading capacity of 3 units in terms of makespan and lateness. When decreasing the loading capacity of MAGVs, both models are still robust to performs better. It is also evident in the S11 model that the NID rule impacts makespan. If the loading capacity is increased and set to 5 units, the S1 models provide a better performance in terms of makespan but has slightly difference against to other models. However, when it comes to lateness, S1, S4 and S6 models stands out among others as seen in Fig. 3 b. For both performance metrics, it is also found that the S7 model produces the worst results in the variability of loading capacity of MAGVs.



a) MAGVs with the loading capacity of 3 in the system b) MAGVs with the loading capacity of 5 in the system

Figure 3: Assessment of the variability in the loading capacity of MAGVs based on simulation models.



a) 2 MAGVs in the system b) 4 MAGVs in the system

Figure 4: Assessment of the variability in the number of MAGVs based on simulation models.

Furthermore, it has been found that the decrease in the number MAGVs in the system results in an increase in the makespan and lateness as expected. As seen in Fig. 4 a, the S8 model outperformed the others in terms of both performance metrics while the S2 model has the worst performance metrics. The S8 is still robust against the decrease in the number of MAGVs. The increase in the number of MAGVs in all models showed a decrease in makespan and lateness. The S4 has the best performance metrics in terms of makespan and lateness while the S7 has the biggest makespan and lateness (see Fig. 4 b). As a result of the S7 model giving priority to the pickup task first, the results worsened. This rule generally causes the most lateness and makespan.

The results indicate that the new rules combined with those for the first, second, and fourth problem increase efficiency. In general, the simulation models that combine the proposed load selection rule with the task determination rule yield better results. In terms of lateness, similar results were obtained. Lateness decreases with increased capacity. Conclusion: among the models, the S4 model gives the best result, while the S2 and S7 models deliver the worst.

4. CONCLUSION

In this study, we are primarily concerned with tasks determination, delivery, and load selection problems associated with MAGV scheduling. In the simulation environment, the proposed novel rules are compared with the most effective rules found in the literature. Further, the proposed rules are subjected to sensitivity analyses to determine how two performance criteria, namely makespan and lateness, are affected by the number of MAGVs at three levels (2, 3, and 4) and the loading capacity of MAGVs at three levels (3, 4, and 5). In order to improve system performance, the proposed NID rule focuses on reducing output queues at stations. As a result of the proposed NID rule, model S4 has a 7 % shorter makespan than model S1, which includes rules provided in the literature. In terms of latency, it performed 72 % better. Using the parameters with the variation in the number of MAGVs, it was concluded that the simulation models including proposed rules gives the best results. All these results suggest that the capacity and number of MAGVs are effective for scheduling. As a result of the proposed three rules out of four problems for MAGVs, better results are obtained. This study does not address the pickup problem since it has been overworked in previous studies and has not been discussed in this study. In future studies, resource breakdowns and vehicle collision for real manufacturing can be taken into consideration. There is no discussion of the machine scheduling and due date assignment algorithm in this study. MAGVs can be used in the future to research the effect of different machine scheduling and due date assignment algorithms on the makespan.

ACKNOWLEDGEMENT

The present study is supported by Scientific Research Project Unit of Çukurova University (CUBAP) (Grant Number: FDK-2015-5354).

REFERENCES

[1] Thonemann, U. W.; Brandeau, M. L. (1996). Designing a single-vehicle automated guided vehicle system with multiple load capacity, *Transportation Science*, Vol. 30, No. 4, 351-363, doi:10.1287/trsc.30.4.351

[2] Azimi, P.; Ghanbari, M. R.; Yarmohammadi, S. (2012). Optimization a multi-objective and multiple-load AGV system using optimization via simulation approach, *International Bulletin of Business Administration*, Vol. 2012, No. 13, 97-108

[3] Sabuncuoglu, I.; Hommertzheim, D. (1989). An investigation of machine and AGV scheduling rules in an FMS, *Proceedings of the Third ORSA/TIMS Conference on Flexible Manufacturing Systems*, 261-266

[4] Ozden, M. (1988). A simulation study of multiple-load-carrying automated guided vehicles in a flexible manufacturing system, *International Journal of Production Research*, Vol. 26, No. 8, 1353-1366, doi:10.1080/00207548808947950

[5] Nayyar, P.; Khator, S. K. (1993). Operational control of multi-load vehicles in an automated guided vehicle system, *Computers & Industrial Engineering*, Vol. 25, No. 1-4, 503-506, doi:10.1016/0360-8352(93)90330-z

[6] Occena, L. G.; Yokota, T. (1993). Analysis of the AGV loading capacity in a JIT environment, *Journal of Manufacturing Systems*, Vol. 12, No. 1, 24-35,doi:10.1016/0278-6125(93)90034-q

[7] Kim, D. B.; Hwang, H. (2001). A dispatching algorithm for multiple-load AGVs using a fuzzy decision-making method in a job shop environment, *Engineering Optimization*, Vol. 33, No. 5, 523-547, doi:10.1080/03052150108940932

[8] Liu, F.-H.; Hung, P.-C. (2001). Real-time deadlock-free control strategy for single multi-load automated guided vehicle on a job shop manufacturing system, *International Journal of Production Research*, Vol. 39, No. 7, 1323-1342, doi:10.1080/00207540010005105

[9] Murayama, N.; Kawata, S. (2006). Simulated annealing method for simultaneous scheduling of machines and multiple-load AGVs, *IJCC Workshop on Digital Engineering*, 55-62

[10] Ho, Y.-C.; Shaw, H.-C. (2000). The performance of multiple-load AGV systems under different guide path configurations and vehicle control strategies, *International Journal of Manufacturing Technology and Management*, Vol. 1, No. 2-3, 218-231, doi:10.1504/ijmtm.2000.001338

[11] Sinriech, D.; Kotlarski, J. (2002). A dynamic scheduling algorithm for a multiple-load multiple-carrier system, *International Journal of Production Research*, Vol. 40, No. 5, 1065-1080, doi:10.1080/00207540110105662

[12] Ho, Y.-C.; Hsieh, P.-F. (2004). A machine-to-loop assignment and layout design methodology for tandem AGV systems with multiple-load vehicles, *International Journal of Production Research*, Vol. 42, No. 4, 801-832, doi:10.1080/00207540310001602874

[13] Ho, Y.-C.; Chien, S.-H. (2006). A simulation study on the performance of task-determination rules and delivery-dispatching rules for multiple-load AGVs, *International Journal of Production Research*, Vol. 44, No. 20, 4193-4222, doi:10.1080/00207540500442401

[14] Ho, Y.-C.; Liu, H.-C. (2006). A simulation study on the performance of pickup-dispatching rules for multiple-load AGVs, *Computers & Industrial Engineering*, Vol. 51, No. 3, 445-463, doi:10.1016/j.cie.2006.08.007

[15] Ho, Y.-C.; Liu, H.-C. (2009). The performance of load-selection rules and pickup-dispatching rules for multiple-load AGVs, *Journal of Manufacturing Systems*, Vol. 28, No. 1, 1-10, doi:10.1016/j.jmsy.2009.06.001

[16] Ho, Y.-C.; Liu, H.-C.; Yih, Y. (2012). A multiple-attribute method for concurrently solving the pickup-dispatching problem and the load-selection problem of multiple-load AGVs, *Journal of Manufacturing Systems*, Vol. 31, No. 3, 288-300, doi:10.1016/j.jmsy.2012.03.002

[17] Li, M. P.; Kuhl, M. E. (2017). Design and simulation analysis of PDER: a multiple-load automated guided vehicle dispatching algorithm, *2017 Winter Simulation Conference (WSC)*, 3311-3322, doi:10.1109/wsc.2017.8248048

[18] Chawla, V. K.; Chanda, A. K.; Angra, S.; Rani, S. (2018). Simultaneous dispatching and scheduling of multi-load AGVs in FMS – a simulation study, *Materials Today: Proceedings*, Vol. 5, No. 11, Part 3, 25358-25367, doi:10.1016/j.matpr.2018.10.339

[19] Lee, C. K. M.; Keung, K. L.; Ng, K. K. H.; Lai, D. C. P. (2018). Simulation-based multiple automated guided vehicles considering charging and collision-free requirements in automatic warehouse, *2018 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 1376-1380, doi:10.1109/ieem.2018.8607396

[20] Guan, J.; Qiu, Z.; Zhou, Y.; Yu, J.; Li, L.; Gui, W. (2018). Scheduling of multi-load automated guided vehicles for material distribution based on multi-stage auction algorithm, *2018 13th World Congress on Intelligent Control and Automation (WCICA)*, 1419-1424, doi:10.1109/wcica.2018.8630350

[21] Angra, S.; Chanda, A. K.; Chawla, V. K. (2018). Comparison and evaluation of job selection dispatching rules for integrated scheduling of multi-load automatic guided vehicles serving in variable sized flexible manufacturing system layouts: a simulation study, *Management Science Letters*, Vol. 8, No. 4, 187-200, doi:10.5267/j.msl.2018.3.002

[22] Boden, P.; Hahne, H.; Rank, S.; Schmidt, T. (2020) Dispatching of multiple load automated guided vehicles based on Adaptive Large Neighborhood Search, Neufeld, J. S.; Buscher, U.; Lasch, R.; Möst, D.; Schönberger, J. (Eds.), *Operations Research Proceedings 2019*, Springer, Cham, 375-380, doi:10.1007/978-3-030-48439-2_45

[23] Yan, R.; Jackson, L.; Dunnett, S. (2020). A study for further exploring the advantages of using multi-load automated guided vehicles, *Journal of Manufacturing Systems*, Vol. 57, 19-30, doi:10.1016/j.jmsy.2020.08.005

[24] Egbelu, P. J.; Tanchoco, J. M. A. (1984). Characterization of automatic guided vehicle dispatching rules, *International Journal of Production Research*, Vol. 22, No. 3, 359-374, doi:10.1080/00207548408942459

[25] Gocken, M.; Dosdogru, A. T.; Boru, A. (2017). Optimization via simulation for inventory control policies and supplier selection, *International Journal of Simulation Modelling*, Vol. 16, No. 2, 241-252, doi:10.2507/IJSIMM16(2)5.375

[26] Thomas, S. K.; Ali, A.; AlArjani, A.; Attia, E.-A. (2022). Simulation based performance improvement: a case study on automotive industries, *International Journal of Simulation Modelling*, Vol. 21, No. 3, 405-416, doi:10.2507/IJSIMM21-3-606

[27] Law, A. M.; Kelton, W. D. (2000). *Simulation Modeling and Analysis*, 3rd edition, McGraw-Hill, New York